On the division of police districts into patrol beats

by SAUL I. GASS
IBM Federal Systems Division
Gaithersburg, Maryland

INTRODUCTION

Recent work done by the Science and Technology Task Force of the President's National Crime Commission included several studies and recommendations which deal with the application of digital computers to the law enforcement and criminal justice fields.[1] A study by C. Walston reviewed the present range of police computer applications; work by the author and others described an approach to the development of a police command and control system; while work by R. Finkler and others described a computer-based criminal justice information system. Early in the Commission's efforts it became apparent that the area of crime is characterized by few reliable statistics and even fewer analytically based rules of procedure. It is the purpose of this paper to bring appropriate problems within the law enforcement area to the attention of the analytical community of computer personnel and to describe an approach to solving one of these problems.

The area of concern can be termed police management decision-making and can be structured into two general problem areas: planning and operations. As we shall see, the range of the specific problems covers a wide gamut of Operations Research/Management Science activities. However, even though some of the problems "look familiar", little has been done to develop an analytical structure for these problems within the field of law enforcement.

In the domain of planning we find the police faced with the following problems:

1. For given demographic parameters—population, level of crime, urban configuration, etc.—how many full-time employees should a police department have and how should they be distributed between patrol, detective and administrative divisions? We find, as a rule of thumb, that the police force in large urban areas consists of about 4 employees per 1000 population and ranges down to about 1 employee per 1000 population in the small cities and towns.[2]
2. Given a force level, how should the manpower be allocated to police districts, shifts and beats over time? Here a key input is the level of crime by type per district and the time necessary to service the different crime types. Recent work by Crowther attacks this problem using queueing and forecasting techniques.[3]
3. How do we measure a police department's effectiveness? Unlike profit-making organizations, the activities of a police department in terms of service to the community cannot be measured in dollars. This problem is compounded by the lack of consensus on what the police should be doing, i.e. what is their job?
4. How should a city be divided into police districts based on demographic and geographic parameters? Should a beat have a one or two-man car, foot patrol or scooter patrol?
5. How should a police district be broken down into individual police patrol beats so that each patrol unit has equal work level? The work level should be divided into answering calls for service and preventitive patrol. In what proportion should the division take? An analytical approach to beat configuration is discussed below.
6. In the long-range planning area we need to determine manpower levels, location of new facilities, contingency riot and other emergency plans, equipment needs, etc. Law enforcement agencies are faced with the full set of planning problems encountered by most service organizations. As noted above, however, the measure of service or "profitability" of law enforcement agencies is an open question.

In the operational area we have the following problems:

1. How to identify a particular pattern of crime which is related to the same criminal or set of criminals?
2. Given that we have identified a particular crime pattern, how do we identify a probable set of suspects?

3. Given someone who has been arrested, how can we determine which crimes (if any) are associated with the suspect?

4. With regard to the geographic distribution of crime, how can we best pre-position special patrols in order to increase the probability of apprehension? How should regular patrols cover their assigned beats in order to increase the probability of apprehension and to increase the patrols' deterrent power? This latter approach, termed dynamic patrol, can be thought of as the development of a random patrol strategy based on the time distribution of crimes.[4,5]

5. How should the limited investigative effort be allocated and to which crimes? A preliminary study by H. Isaacs for the Crime Commission reveals that the investigative force usually works on those crimes which have a solid clue e.g., named suspect, auto license plate number, and do little Sherlock Holmes type work on the run-of-the-mill crime. Work by Willmer discusses an information theory approach to the value of clues in police investigations.[6]

6. Given a call for police services, which unit should be selected to respond? As police forces respond to such calls, how should the remaining forces be dynamically re-allocated based on current and expected demands?

Many of the above problems fall into the realm of Operations Research and the reader is referred to the bibliography for discussions on these and other problems in the law enforcement field. In particular, we shall discuss the work by Hess, et al as it relates to one of the above problems—the determination of patrol beats—and describe some computational results.[7]

Structuring of Police Beats

The basic problem is as follows: Given k patrol units to be assigned during a patrol shift, how should the k corresponding patrol beats be determined so that each patrol unit will, on the average, have the same workload? The area of a patrol beat must be contiguous to itself and of such a shape to allow for efficient patrol and response tactics. (A long, narrow beat or a star-shaped beat would not be too efficient. Preliminary studies by R. Larson have demonstrated the advantage of square-shaped beats.[8] Of course, geographical and political constraints often help shape a beat.)

The International Association of Chiefs of Police (IACP) recommends taking each zone of the city—usually census tracts—and measuring in some sense, the total crime workload in each zone. Then, using heuristics, combining the tracts to form k contiguous beats having approximately the same relative workload. To determine the workload for a tract, weights are given to the various incidents (investigate a criminal act, arrest of a suspect) to yield the weighted workload for a tract. The weights tend to reflect the importance of the incident and the time required by a patrol unit to process the incident. (We assume we have already determined that for a particular shift, the total expected workload for the city requires k patrol units. This determination is, of course, a challenging problem in itself.) The IACP uses the following weights:

Type of Incident	Relative Weight
Criminal Homicide	4
Forcible Rape	4
Robbery	4
Aggravated Assault	4
Burglary	4
Larceny	4
Auto Theft	4
All Other Offenses	3
Arrests for all offenses except drunkeness	2
Traffic Accidents	2
Arrests for Drunkeness	1
Miscellaneous Police Services	1

The first seven types of incidents are called Index Crimes as they represent the main categories of crimes reported in the FBI's Uniform Crime Report.

Our approach to the determination of patrol beats is to attempt to employ analytical procedures for the structuring of the k beats. The development of such procedures will become more important as police departments move into real-time computer-based systems for the reporting and dispatching functions. Such systems will enable the capturing and analysis of the necessary data for more frequent updating of patrol procedures. Thus, to make dynamic and effective use of such data, a wide range of analytical procedures which address the problems discussed above is a must. New York City's planned Project SPRINT (Special Police Radio Inquiry Network) is the first of such computer-based systems.

From the field of Operations Research we find a situation analogous to the determination of patrol beats, the warehouse location problem. Here, we wish to locate a specified number of warehouses and assign customers to each warehouse such that the total cost of servicing the customers from their assigned warehouses is minimized. Here the cost could include transportation, delivery and customer relations. This problem definition has recently been extended to include the problem of reapportioning a state into legislative political districts.[7] The problem is to locate a specified number of district centers and assign population units to each district such that the assigned district population must be nearly equal—the one man, one vote concept. The cost, or more correctly, the measure of effectiveness of a set of centers and assignments was taken to be the population moment of inertia, i.e. minimize the sum of the squared distance of each person to his district center. The computational procedure must, along with the measure of effectiveness, allow for the need for contiguous districts (no gerrymanders) and for compact districts (more square than rectangular). We propose to extend this formulation and associated computational procedure to the structuring of police beats.

Mathematically, the problem can be formulated as an integer programming problem, Hess, et al, although the formulation does not necessarily take care of the contiguity requirement.[7] This requirement causes the computational procedure used by Hess, et al to be a combination of an analytical procedure (basically the transportation algorithm) and an automated heuristic adjustment. In terms of weighted crime, using their formulation, we can state the problem as

Minimize

$$\sum_{i=1}^{n} \sum_{j=1}^{n} (d_{ij}^2 c_j)\, x_{ij}$$

subject to

$$\sum_{i=1}^{n} x_{ij} = 1 \qquad j = 1,2,\ldots,n$$

$$\sum_{i=1}^{n} x_{ii} = k$$

$$\sum_{j=1}^{n} c_j x_{ij} \geq \frac{aC}{k} x_{ii} \qquad i = 1,2,\ldots,n$$

$$\sum_{j=1}^{n} c_j x_{ij} \leq \frac{bC}{k} x_{ii} \qquad i = 1,2,\ldots,n$$

$$x_{ij} = 0 \text{ or } 1,$$

where

k = *number of beats to be assigned*

n = *number of census tracts in city*

$$x_{ij} = \begin{cases} 1 & \text{if tract } T_j \text{ is assigned to the beat centered about tract } T_i \\ 0 & \text{otherwise} \end{cases}$$

c_j = *the weighted crime workload in T_j, e.g. if I_{pj} = level of crime incident p in T_j then $c_j = \sum_p w_p I_{pj}$, where w_p is the weight of the p^{th} incident.*

$$C = \sum_{j=1}^{n} c_j = \text{total weighted crime in city}$$

$\frac{C}{k}$ = *average weighted crime per beat*

a = *factor for minimum allowable crime in a beat with respect to average crime per beat.*

b = *factor for maximum allowable crime in a beat with respect to average crime per beat.*

d_{ij} = *distance between centers of T_i and T_j census tracts.*

$d_{ij}^2 c_j$ = *moment of inertia of the weighted crimes in T_j about the center of tract i.*

Our measure of effectiveness is then $\sum_i \sum_j (d_{ij}^2\, c_j)\, x_{ij}$, which can be interpreted as the total moment of inertia of the weighted crimes about the k centers. (We assume that a beat center will also be the center of some tract T_i.)

We propose not to solve the integer problem, but to apply the analytic-heuristic procedure of Hess, et al to a particular city using actual crime statistics. We used data from the 1966 annual report of the Cleveland Police Department. Our approach was to employ a number of different measures of effectiveness which relate total crime, population, and area of each census tract interpreted as an appropriate moment of inertia. The results, compared to the actual 1966 beat structures, are shown below.

Computational Results

Again, the basic problem is to combine the census tracts of the City of Cleveland, Figure 1, to form contiguous and compact beats. Figure 1 also shows the actual boundaries of the 1966 beats. There were a total k = 58 beats and n = 205 census tracts to assign. Tables 1a and 1b show the number and percentage of index crimes in each of the 1966 beats and the ranking position in terms of index crimes. The reader will note the wide variations in terms of crime rate, population and area of the beats. Table 2a and 2b show the level of index crimes in each census tract. In our computations we used five measures of the workload for a census tract: number of index crimes, population, area, level of crime multiplied by the population, and the level of crime multiplied by the area. It is felt that the workload in a patrol beat is some function of these three elements—plus related demographic and geographic data. We have used these rather basic measures as a start in order to obtain more experience on how the analytic-heuristic procedure develops contiguous and comparable beats. In the computations, we kept the

Census Tracts in Cleveland, Ohio
and 1966 Police Beats

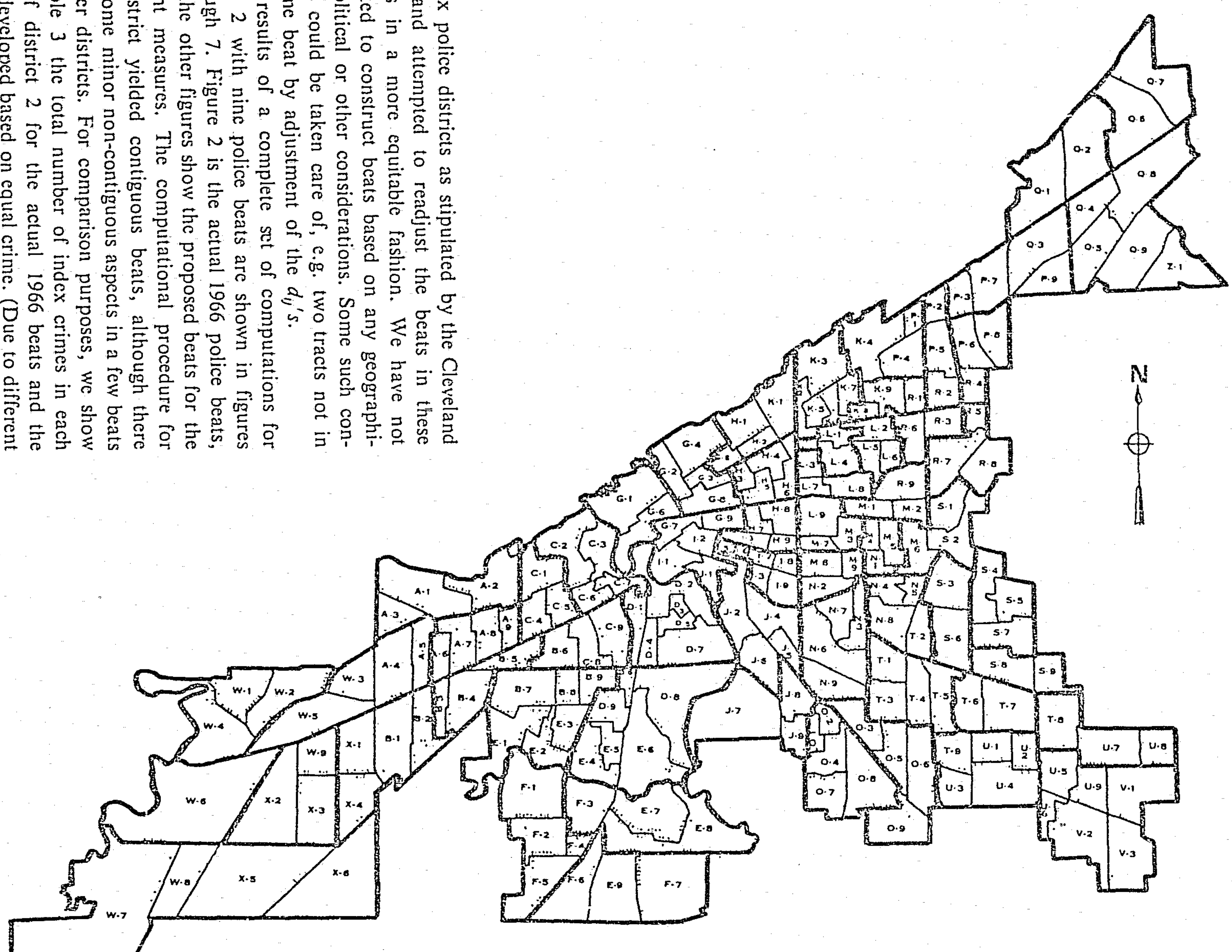


Figure 1.

same six police districts as stipulated by the Cleveland police and attempted to readjust the beats in these districts in a more equitable fashion. We have not attempted to construct beats based on any geographical, political or other considerations. Some such constraints could be taken care of, e.g. two tracts not in the same beat by adjustment of the d_{ij}'s.

The results of a complete set of computations for district 2 with nine police beats are shown in figures 2 through 7. Figure 2 is the actual 1966 police beats, while the other figures show the proposed beats for the different measures. The computational procedure for this district yielded contiguous beats, although there were some minor non-contiguous aspects in a few beats in other districts. For comparison purposes, we show in Table 3 the total number of index crimes in each beat of district 2 for the actual 1966 beats and the beats developed based on equal crime. (Due to different population and unavailability of data, such comparisons cannot be made for the other measures.) Table 4 shows for the five measures the amount of the total measure for each of the nine beats.

TABLE 1a

DISTRICT	ZONE	CENSUS TRACT	PERCENTAGE	POSITION	TOTAL	MURDER	RAPE AND ASSAULT TO ROB	ROBBERY AND ASSAULT TO ROB	ASSAULTS	BREAKING AND ENTERING	LARCENIES	AUTO THEFT	POPULATION	ACREAGE	SQUARE MILES
FIRST	101	A1,2,3	1.4	33	456	3	2	29	57	106	167	92	13,974	810	
	102	A6,7,8,9	1.5	31	473	3	3	27	35	99	203	103	16,337	555	
	103	B3,4,5	0.8	47	272	1	1	11	30	57	119	53	15,445	523	
	104	A4,5,W3,5	2.2	12	706		1	12	34	105	424	130	17,183	1,151	
	105	B1,2,X1,4	1.0	43	331		1	16	31	93	152	38	21,773	1,128	
	106	W1,2,4	0.7	48	229			3	19	48	117	42	14,584	1,258	
	107	W9,X2,X3	0.6	50	208	2		3	18	41	108	36	16,347	1,175	
	108	W6	0.7	49	213	1		4	10	44	128	26	12,493	1,251	
	109	W7,8,X5,6	1.3	36	426	2	2	6	22	71	254	69	23,051	4,787	
	Total		10.2		3,314	12	10	111	256	664	1,672	589	151,187	12,638	19.3656
SECOND	201	C2,3,6,7	1.7	23	539	1	1	30	57	101	270	79	10,803	695	
	202	C1,4,5	1.3	35	429	3		26	52	83	145	120	13,472	458	
	203	B6,C8,9	1.6	24	531	5	2	19	57	117	207	124	15,661	620	
	204	D1,2,3,4,5,7	1.6	25	520	2	3	18	70	122	190	115	14,849	1,109	
	205	D6,8,9,E4,5,6	1.7	22	545	1	2	24	35	107	222	154	23,518	1,726	
	206	B7,8,9,E1,2,3	1.8	20	571	1		23	48	89	271	139	22,320	1,267	
	207	F3,E7,8	0.8	46	277		2	11	21	51	145	47	14,481	1,302	
	208	F1,2,4,5	0.9	45	291		1	7	10	36	183	54	15,163	1,057	
	209	F6,7,E9	0.6	51	186			8	11	41	86	40	14,365	1,324	
	Total		12.0		3,889	13	11	166	361	747	1,719	872	144,632	9,558	14.93
THIRD	301	G1,6	3.6	4	1,158		1	50	78	150	635	244	474	579	
	302	G2,3,4,8	2.4	9	781	2	1	39	61	96	378	204	2,635	446	
	303	G5,H1,2,K1	1.1	40	368		3	15	28	94	137	91	3,737	506	
	304	H3,4,5,6	1.9	17	604		2	45	33	104	277	143	6,964	445	
	305	H7,8,9,13	2.5	8	809	3	3	97	121	111	300	174	11,862	375	
	306	G7,9,I1,2,J1	4.7	2	1,518	3	3	57	53	177	907	315	2,818	676	
	307	I5,6,7,8,9,J3	1.4	32	459	3		44	48	89	157	118	7,665	399	
	308	J2,4,5,6	0.6	53	179		1	6	29	28	84	31	4,053	818	
	309	J7,8,9	0.5	54	176	1		13	23	45	61	36	8,436	960	
	Total		18.7		6,052	12	14	366	474	894	2,936	1,356	48,644	5,204	8.13

TABLE 1b

DISTRICT	ZONE	CENCUS TRACT	PERCENTAGE	POSITION	TOTAL	MURDER	RAPE AND ASSAULT TO RAPE	ROBBERY AND ASSAULT TO ROB	ASSAULTS	BREAKING AND ENTERING	LARCENIES	AUTO THEFT	POPULATION	ACREAGE	SQUARE MILES
FOURTH	401	N3,6,7,9	1.5	29	498	2	5	36	71	127	140*	117	15,710	891	
	402	O1,2,4,7,8	1.3	37	417		1	18	28	93	196	81	18,514	927	
	403	N4,5,8,T2	1.8	19	576	5	5	86	84	87	174	135	12,099	618	
	404	T1,3,4,5	1.2	39	396	1	2	34	39	76	163	81	12,890	796	
	405	O3,5,6,9	1.1	42	361			17	30	106	140	68	15,764	1,037	
	406	S3,6,	1.3	37	417		1	30	30	55	186	115	11,640	605	
	407	S4,5,7	1.8	18	584	3	4	39	17	77	302	142	18,335	737	
	408	S8,9,	1.1	41	365	2	2	27	31	95	110	98	12,604	408	
	409	T6,7,	1.5	30	480	5	1	44	52	123	128	127	15,335	530	
	410	T9,U1,2,3,4	1.7	21	565	2	3	42	37	111	243	127	19,798	1,007	
	411	T8,U7,8	1.3	38	416	2	1	17	46	98	161	91	18,293	769	
	412	U5,6,9,V1,2,3	1.9	16	612		3	32	50	166	243	118	19,541	1,659	
	Total		17.5		5,687	22	28	422	515	1,214	2,186	1,300	190,523	9,984	15.6
FIFTH	501	L1,4	2.3	10	759	7	10	155	158	144	157	128	15,268	279	
	502	L3,7,8	3.8	3	1,220	8	10	205	245	288	301	163	12,732	298	
	503	L2,5,6	2.6	7	837	8	5	153	177	198	147	149	15,872	315	
	504	M1,2,R9	5.6	1	1,812	9	13	277	211	323	625	354	14,193	426	
	505	L9,M3,7	2.3	11	730	8	4	95	111	150	201	161	10,256	385	
	506	M8,9,N2	1.5	31	473	2	6	65	92	117	97	94	7,679	363	
	507	M4,5,N1,	1.5	28	500	6	5	41	70	116	95	167	11,895	281	
	508	R3,6	2.0	14	646	4	2	67	91	149	171	162	13,047	358	
	509	R5,7,8	1.6	27	510	4	4	44	73	107	167	111	12,915	653	
	510	M6,S1,2	1.9	15	632		1	92	78	93	207	161	10,007	641	
	Total		25.1		8,119	56	60	1,194	1,306	1,685	2,168	1,650	123,864	3,999	6.248
SIXTH	601	K2,3,5,6,7	1.3	34	430	1	2	60	41	91	165	70	14,309	590	
	602	K4,P1,4	2.1	13	677	2	6	65	93	182	183	146	17,382	688	
	603	K8,9,R1	1.5		480	1	4	72	79	96	115	113	12,631	329	
	604	P2,5,R2,	2.8	6	893	5	5	94	100	225	260	204	19,644	465	
	605	P6,8,R4	3.2	5	1,024	7	10	95	134	239	249	290	23,283	560	
	606	P3,7,9,Q3	2.5	8	809	4	1	46	73	162	253	270	21,279	946	
	607	Q4,5,8,9,Z1	1.6	26	515	1	2	15	33	135	178	151	20,537	1,818	
	608	Q1,2,	0.9	44	301	2		13	18	55	134	79	12,151	911	
	609	Q6,7	0.6	52	181	1		7	9	46	76	42	10,792	985	
	Total		16.5		5,310	24	30	467	580	1,231	1,613	1,365	152,008	7,292	11.39
	GRAND TOTAL		100.0		32,371	139	153	2,726	3,492	6,435	12,294	7,132	810,858	48,675	75.6636
	UNKNOWN LOCATIONS				353		6	6	24		317				
	TOTAL REPORTED CRIMES				32,724	139	159	2,732	3,516	6,435	12,611	7,132			

Further research on the structuring of police beats with equal workloads using this system is required in order to define a proper definition of workload. For example, due to the lack of data, the measure and weighting scheme proposed by the IACP could not be evaluated. It is planned to imbed the police beat algorithm within a geographical crime information system with graphical inputs and outputs, thus enabling us to bring the proper man-machine interaction to bear on this heuristic-analytic type of decision problem. In

TABLE 2a

MAJOR CRIMES BY CENSUS TRACT – YEAR 1966

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
A1			11	15	45	62	45
A2	2	2	15	29	36	65	21
A3	1		3	13	25	40	26
A4		1	8	8	7	118	39
A5			2	10	25	33	20
A6	2	1	3	7	8	39	18
A7	1		6	13	39	84	33
A8			7	11	30	44	35
A9		2	11	4	22	36	17
B1			5	11	38	56	17
B2			3	3	10	24	6
B3		1		7	14	24	4
B4			6	9	16	50	21
B5	1		5	14	27	45	28
B6	1	1	4	25	32	77	43
B7	1		5	20	27	75	30
B8			2	8	10	43	23
B9			5	7	18	38	21
C1	2		4	8	16	48	30
C2			8	7	13	54	16
C3		1	6	16	26	71	13
C4			16	31	39	55	46
C5	1		6	13	28	42	44
C6	1		11	29	45	100	36
C7			5	5	17	45	14
C8	2		3	14	37	45	30
C9	2	1	12	18	48	85	51
D1			7	24	36	47	33
D2	1	2	4	8	24	44	22
D3	1		2	6	17	14	9
D4			1	7	17	17	19
D5			3	16	13	22	5
D6			5	9	13	30	22
D7		1	1	9	15	46	27
D8		1	5	5	17	29	20
D9		1	5	2	23	26	24

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
E1			8	7	16	76	41
E2			2	4	6	15	9
E3			1	2	12	24	15
E4			4	6	13	44	24
E5			1	3	17	42	20
E6	1		4	10	24	51	44
E7		1	6	5	14	45	13
E8		1	3	9	21	48	18
E9			6	8	20	25	12
F1			3	3	15	87	10
F2		1	2	2	10	36	23
F3			2	7	16	52	16
F4				3	2	6	4
F5			2	2	9	54	17
F6			1	3	16	36	19
F7			1		5	25	9
G1		1	19	43	42	249	100
G2			4	9	24	76	52
G3			1	5	19	35	31
G4				2	3	28	10
G5			7	12	10	21	16
G6			31	35	108	386	144
G7	3		34	39	117	696	216
G8	2	1	34	45	50	239	111
G9		2	20	15	42	146	55
H1			1	3	28	45	19
H2		2	1	3	20	22	17
H3			5	5	18	35	16
H4		1	4	10	31	48	28
H5			11	5	18	121	57
H6		1	25	13	37	73	42
H7	3		18	20	33	65	26
H8			39	39	50	160	73
H9			20	23	18	33	43

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
I1		1		1	6	14	8
I2			2	1	5	32	30
I3		3	20	29	10	42	32
I5			1	1	3	5	4
I6			1		1	1	2
I7			20	10	36	42	44
I8	1		17	27	30	43	40
I9	2		1	9	14	39	13
J1			1		7	19	6
J2			1	6	4	20	8
J3			4	1	5	27	15
J4			4	9	13	26	7
J5		1	1	8	6	27	10
J6				6	5	11	6
J7			3	1	4	8	8
J8	1		8	17	39	36	17
J9			2	2	2	17	11
K1		1	6	10	36	49	39
K2			21	15	27	22	25
K3		1	8	4	25	78	12
K4		5	18	31	55	85	67
K5	1	1	4	3	16	19	11
K6			25	8	11	17	11
K7			2	11	12	29	11
K8	1	1	36	20	21	31	31
K9		3	18	22	23	39	50
L1	2	5	66	48	52	69	49
L2	2	2	38	52	67	55	48
L3	3	3	33	48	49	46	36
L4	5	5	89	110	92	88	79
L5	1	2	87	87	86	58	58
L6	5	1	28	38	45	34	43
L7	2	3	33	43	56	48	26
L8	3	4	139	154	183	207	101
L9	5	1	52	46	60	124	100

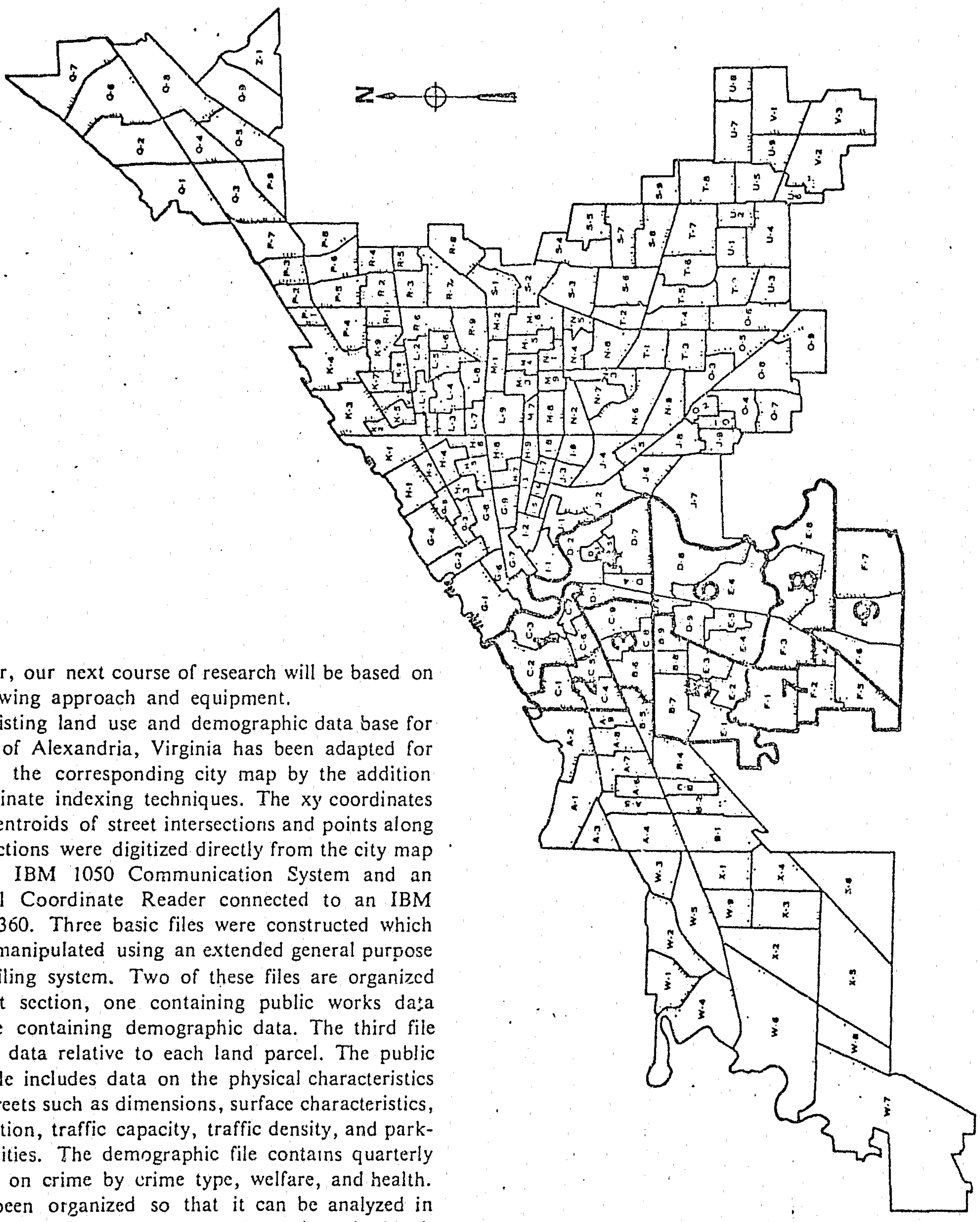
TABLE 2b

MAJOR CRIMES BY CENSUS TRACT – YEAR 1966

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
M1	3	2	78	72	91	225	129
M2		4	58	39	67	129	94
M3	3	2	21	46	44	32	29
M4	3	1	19	27	23	34	38
M5	2	1	11	23	45	28	81
M6		1	20	18	30	31	54
M7		1	22	19	46	45	32
M8	1	3	48	62	58	57	41
M9			3	4	18	8	23
N1	1	3	11	20	48	33	48
N2	1	3	14	26	41	32	30
N3	1	1	16	32	56	40	64
N4			21	27	16	42	42
N5	1	1	29	10	23	47	34
N6			7	9	25	31	21
N7	1	2	5	11	28	25	20
N8	3	2	26	41	29	41	41
N9		2	8	19	18	44	12
O1		1	4	6	9	14	7
O2			3	8	9	22	21
O3			5	10	28	31	21
O4			4	5	16	53	8
O5			3	7	31	52	25
O6			5	10	29	32	15
O7			2	3	7	22	6
O8			5	6	52	85	39
O9			4	3	18	25	7
P1	1	1	13	22	43	27	25
P2	1	3	21	14	38	92	36
P3	2		14	14	40	55	67
P4	1		34	40	84	71	54
P5	2	1	38	58	141	93	100
P6	2	6	26	61	84	87	86
P7	2	1	13	23	46	76	89
P8	5	3	39	38	118	119	159
P9			7	11	31	54	37

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
Q1	2		7	7	22	76	39
Q2			6	11	33	58	40
Q3			12	25	45	68	77
Q4	1		3	3	25	27	36
Q5		2	1	10	19	37	30
Q6			3	2	19	23	17
Q7	1		4	7	27	53	25
Q8			9	9	41	28	24
Q9			2	11	43	71	56
R1			18	37	52	45	32
R2	2	1	35	28	46	75	68
R3	2	1	25	36	67	62	56
R4		1	30	35	37	43	45
R5	1	2	18	28	39	22	34
R6	2	1	42	55	82	109	106
R7	2	2	19	28	44	100	62
R8	1		7	17	24	45	15
R9	6	7	141	100	165	271	131
S1			59	51	44	158	99
S2			13	9	19	18	8
S3		1	14	16	27	131	99
S4		1	8	4	19	87	34
S5		1	12	5	32	158	66
S6			16	14	28	55	16
S7	3	2	19	8	26	57	42
S8	2	1	17	20	59	58	67
S9		1	10	11	36	52	31
T1	1		6	17	26	42	22
T2	1	2	10	6	19	44	18
T3		1	2	3	8	35	12
T4		1	15	11	19	46	25
T5			11	8	23	40	22
T6	3		31	30	54	50	59
T7	2	1	13	22	69	78	68
T8	1	1	10	24	44	71	40
T9			6	2	13	32	26

CENSUS TRACT	MURDER	RAPE & ASSAULT TO RAPE	ROBBERY & ASSAULT TO ROB	ASSAULTS	BREAKING & ENTERING	LARCENIES	AUTO THEFT
U1		1	14	14	20	49	20
U2	2	2	10	10	20	28	18
U3					12	21	9
U4			12	11	46	113	54
U5		1	10	9	20	42	27
U6			2	3	4	48	13
U7	1		7	17	44	76	42
U8				5	10	14	9
U9		1	8	9	19	23	17
V1			6	15	34	86	33
V2		1	5	5	24	29	19
V3			1	9	65	15	9
W1				5	8	25	2
W2				6	17	36	31
W3			1	2	13	95	10
W4			3	8	23	56	9
W5			1	14	60	178	61
W6	1		4	10	44	128	26
W7	1	1	2	8	22	102	34
W8			2	3	6	17	11
W9	2			6	14	25	3
X1		1	2	5	32	56	11
X2			3	5	22	48	26
X3				7	5	35	7
X4			6	12	13	16	4
X5			1	7	26	58	16
X6	1	1	1	4	17	77	8
Z1					7	15	5

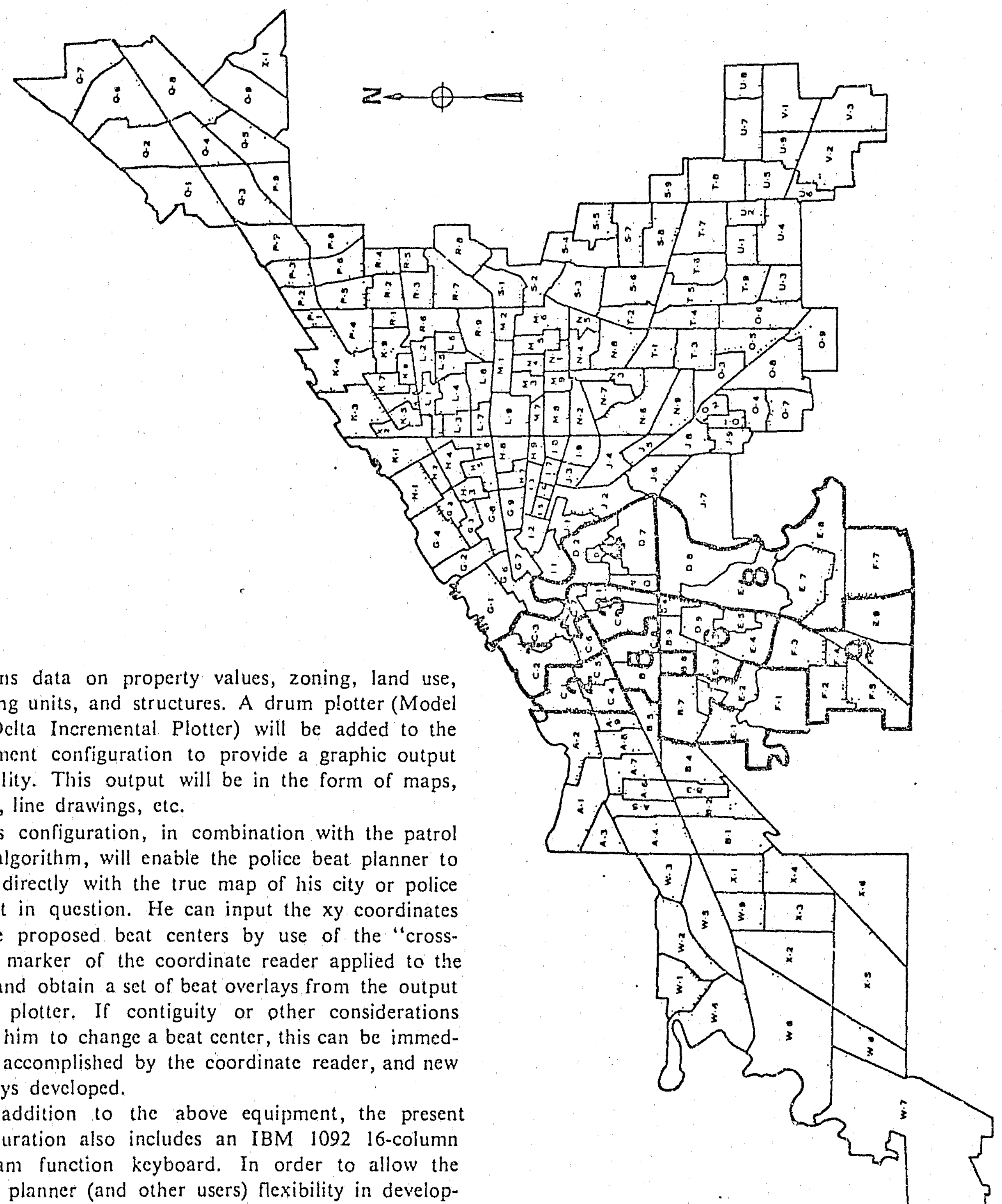


particular, our next course of research will be based on the following approach and equipment.

An existing land use and demographic data base for the city of Alexandria, Virginia has been adapted for use with the corresponding city map by the addition of coordinate indexing techniques. The xy coordinates of the centroids of street intersections and points along street sections were digitized directly from the city map using an IBM 1050 Communication System and an Auto-trol Coordinate Reader connected to an IBM System 360. Three basic files were constructed which can be manipulated using an extended general purpose file-handling system. Two of these files are organized by street section, one containing public works data and one containing demographic data. The third file contains data relative to each land parcel. The public works file includes data on the physical characteristics of the streets such as dimensions, surface characteristics, signalization, traffic capacity, traffic density, and parking facilities. The demographic file contains quarterly statistics on crime by crime type, welfare, and health. It has been organized so that it can be analyzed in conjunction with census data aggregated to the block face adjoining each side of the street. The parcel file

Figure 2.

Census Tracts in Cleveland, Ohio
Police Beats Based on Equal Crime
District 2



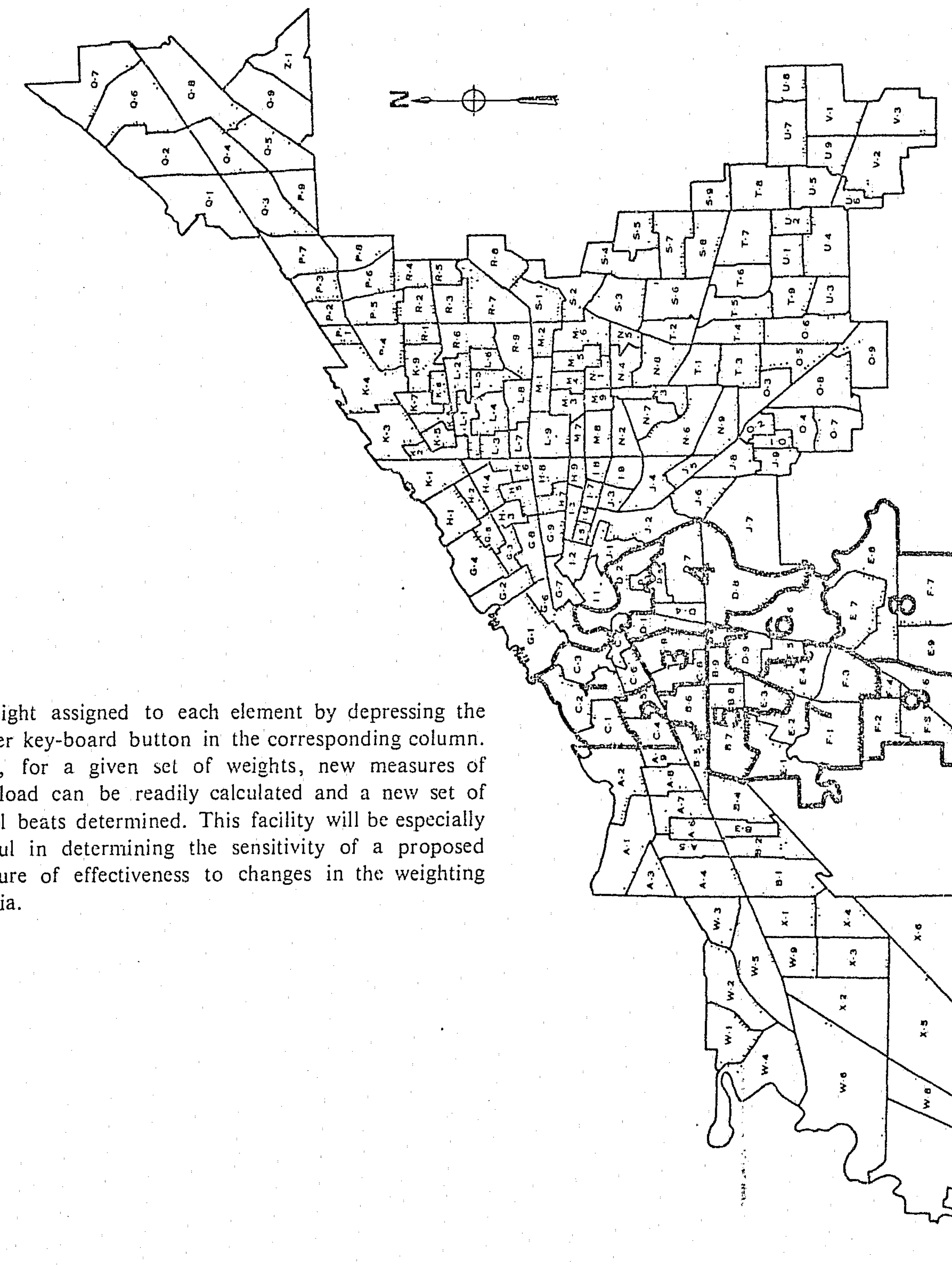
contains data on property values, zoning, land use, dwelling units, and structures. A drum plotter (Model 345 Delta Incremental Plotter) will be added to the equipment configuration to provide a graphic output capability. This output will be in the form of maps, charts, line drawings, etc.

This configuration, in combination with the patrol beat algorithm, will enable the police beat planner to work directly with the true map of his city or police district in question. He can input the xy coordinates of the proposed beat centers by use of the "cross-hair" marker of the coordinate reader applied to the map and obtain a set of beat overlays from the output drum plotter. If contiguity or other considerations cause him to change a beat center, this can be immediately accomplished by the coordinate reader, and new overlays developed.

In addition to the above equipment, the present configuration also includes an IBM 1092 16-column program function keyboard. In order to allow the police planner (and other users) flexibility in developing the proper measures of effectiveness, each column can be assigned a particular demographic or other element (e.g. murder, street miles, welfare cases) and

Figure 3.

Census Tracts in Cleveland, Ohio
Police Beats Based on Equal Population
District 2



a weight assigned to each element by depressing the proper key-board button in the corresponding column. Thus, for a given set of weights, new measures of workload can be readily calculated and a new set of patrol beats determined. This facility will be especially helpful in determining the sensitivity of a proposed measure of effectiveness to changes in the weighting criteria.

Figure 4.

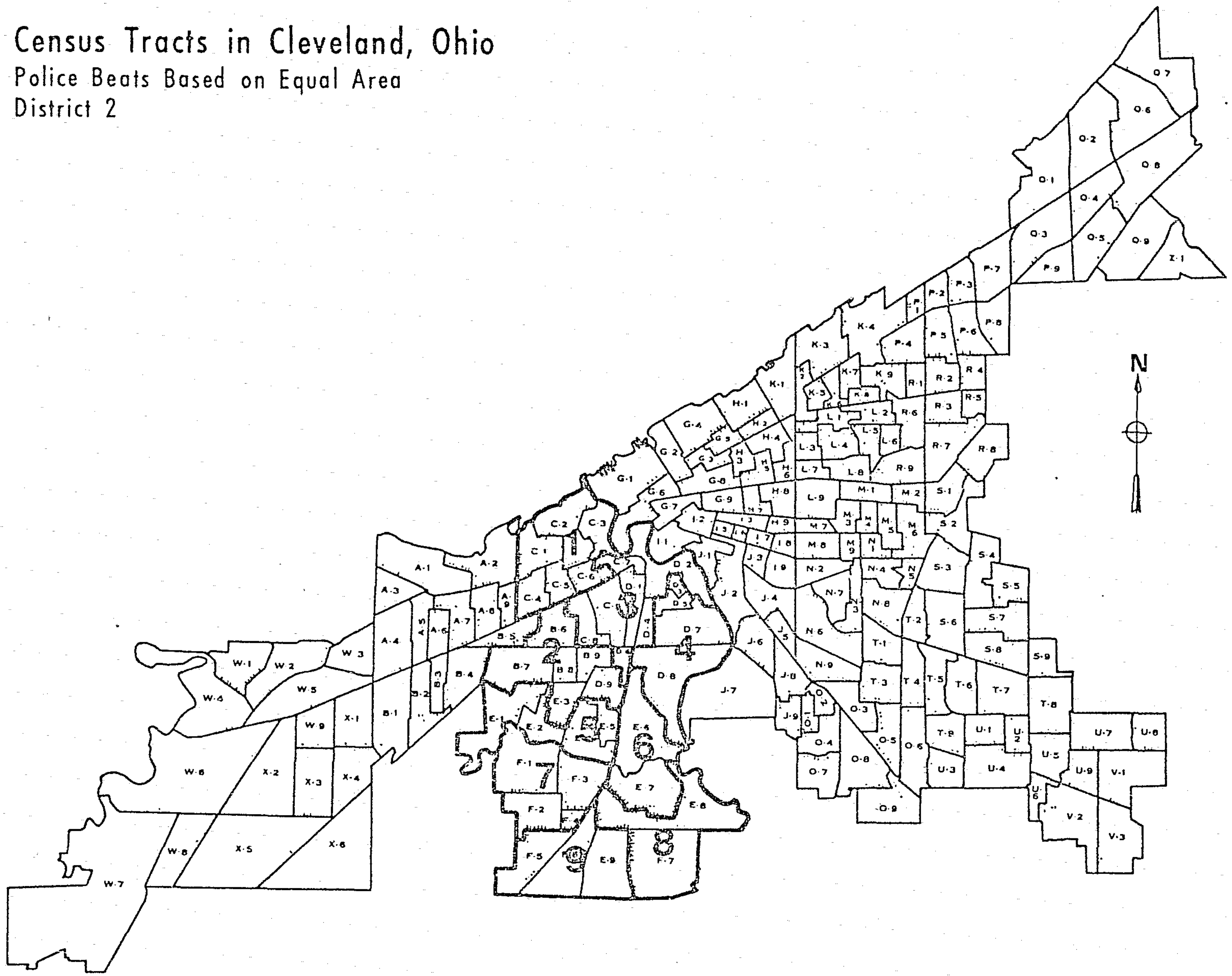

Census Tracts in Cleveland, Ohio
Police Beats Based on Equal Area
District 2
N

Figure 5.

Census Tracts in Cleveland, Ohio
Police Beats Based on Equal Crime Times Population
District 2

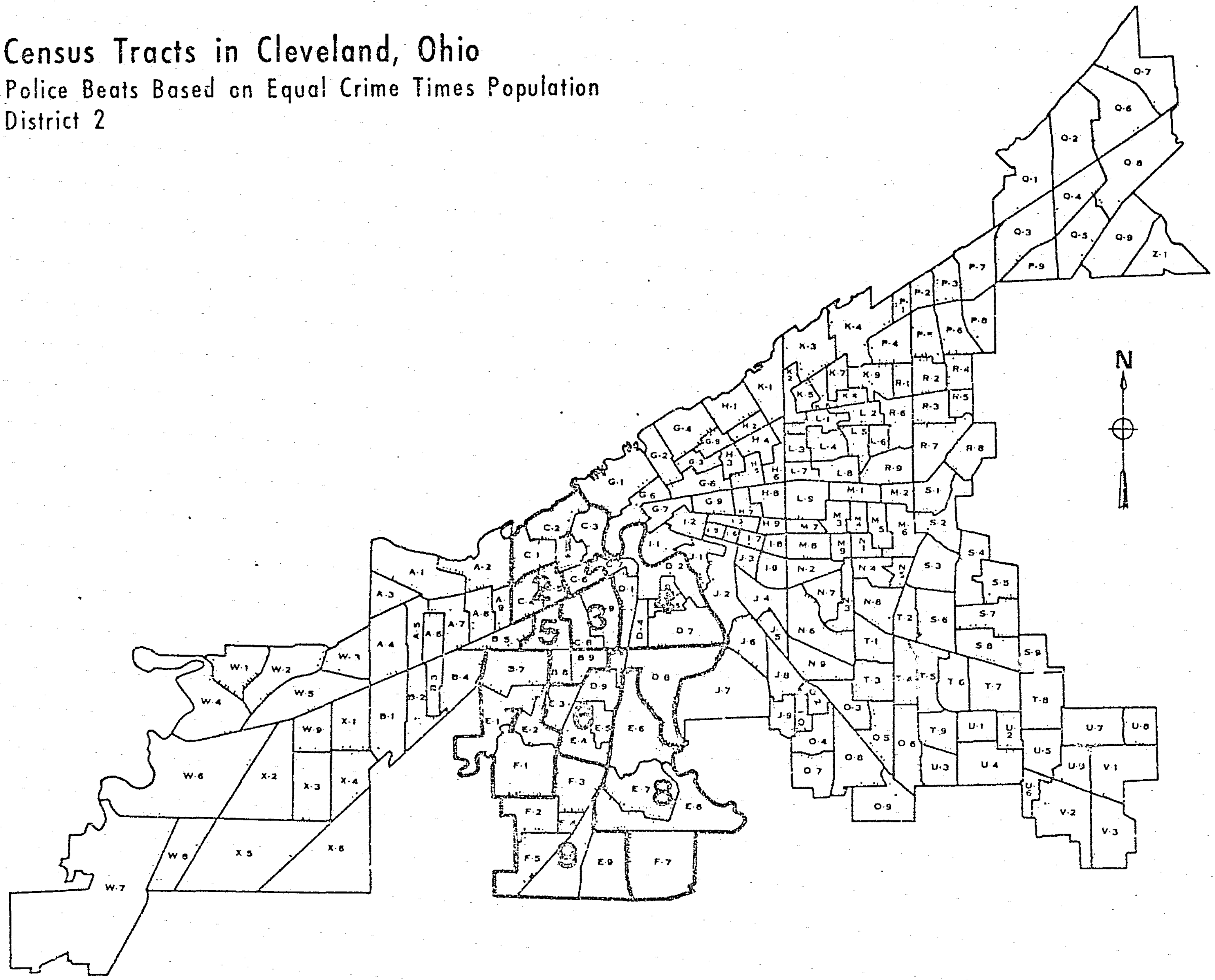


Figure 6.

Census Tracts in Cleveland, Ohio

Police Beats Based on Equal Crime Times Area
District 2

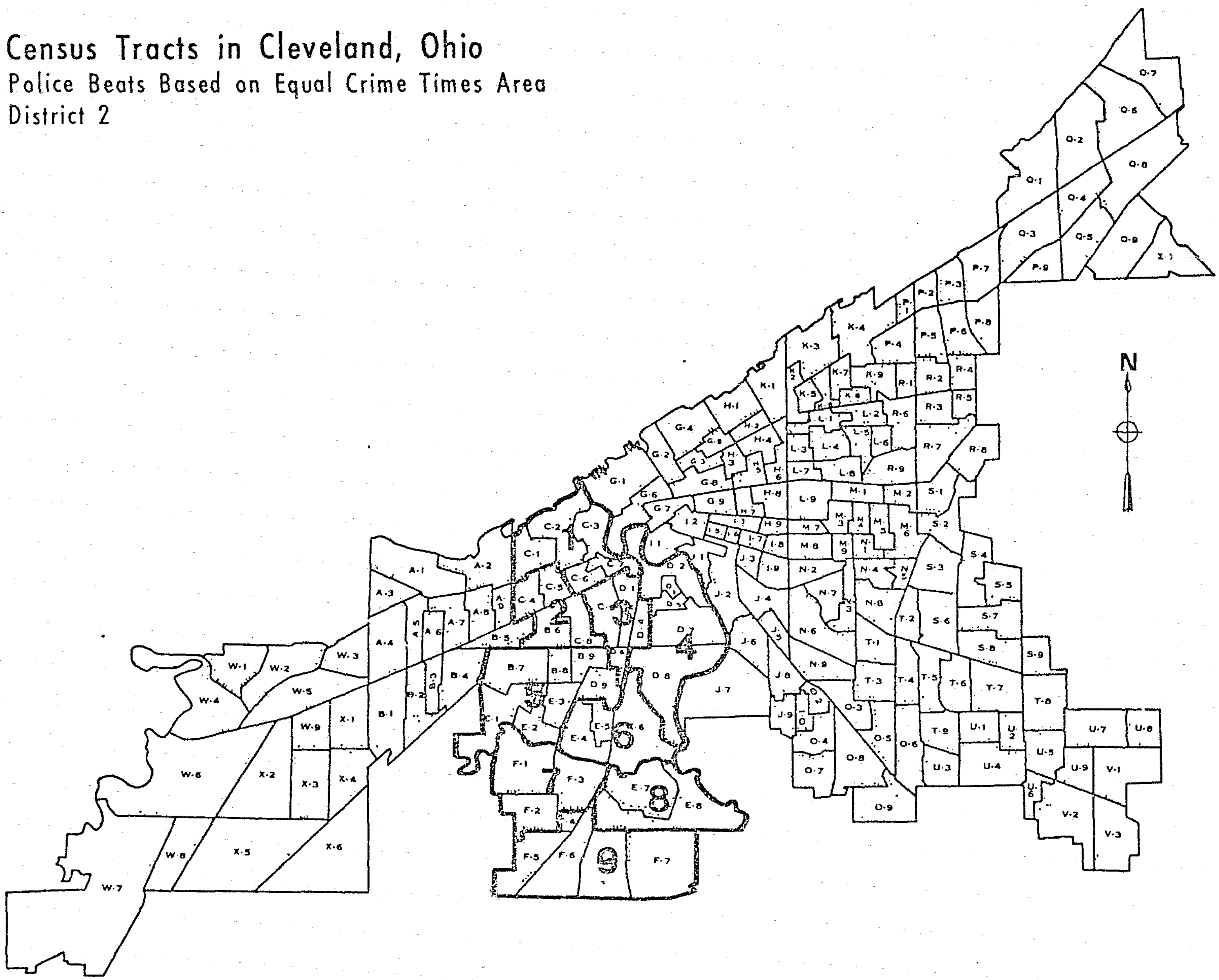


Figure 7.

TABLE 3

No. of Index Crimes Per Beat (District 2)

Beats	1966 Actual	Equal Crime (Fig. 3)
1	539	453
2	429	429
3	531	460
4	520	373
5	545	400
6	571	478
7	277	477
8	291	435
9	186	421
	3,889*	3,926*

*Difference in totals attributed to errors in data preparation.

TABLE 4

Comparison of Measures

Beats	Crime (C)	Population (P)	Area (A)	$CP/10^3$	CAx 10
1	453 crimes	19306 people	1.159 sq. miles	2010	1145
2	429	16417	1.210	1872	1182
3	460	14530	1.189	2216	942
4	373	19272	1.136	1962	1276
5	400	17864	1.047	1507	1209
6	478	14922	1.017	1960	1123
7	477	20083	1.207	2227	1135
8	435	18604	1.308	1961	1008
9	421	15715	1.234	1800	1256
Desired Average	436	17413	1.167	1946	1142

REFERENCES

1 *Science and technology task force report*
The President's Commission on Law Enforcement and Criminal Justice Government Printing Office Washington D C 1967

2 *Uniform crime report*
FBI Washington D C 1966

3 R F CROWTHER
The use of a computer system for police manpower allocation in St. Louis Missouri
Department of Police Administration Indiana University

4 M ROSENSHINE
Random patrol scheduling
Cornell Aeronautical Laboratory Buffalo N Y

5 J F ELLIOTT
Random patrol
Electronics Laboratory General Electric Syracuse N Y

6 M A P WILLMER
On the measurement of information in the field of criminal detection
Operational Research Quarterly Vol 17 No 4

7 HESS et al
Nonpartisan political redistricting by computer
Operations Research Vol 13 No 6

8 R LARSON
Operational study of the police response system
Tech Report No 26 O R Center MIT Dec 1967

9 E B MODE
Probability and criminalistics
American Statistical Association Journal September 1963

10 M E WOLFGANG and H A SMITH
Mathematical methods in criminology
International Social Science Journal Vol XVIII No 2 1966

11 A C McDONALD
The use of gaming techniques in police research
SA/Pol 12 Home Office London England

12 M A P WILLMER
Criminal investigation from the small town to the large urban conurbation
SA/PM 5 Home Office London England

13 W J BAUMOL and P WOLFE
A warehouse-location problem
Operations Research Vol 6 pp 252-263

14 M R ROSENTHAL and S B SMITH
The m-center problem
Report Illinois Institute of Technology Chicago Illinois

15 A A KUEHN and M J HAMBURGER
A heuristic program for locating warehouses
Management Science Vol 9 pp 643-666

16 R P SHUMATE and R F CROWTHER
Quantitative methods for optimizing the allocation of police resources
Journal of Criminal Law Criminology and Police Science Vol 57 No 2

17 D E CLAPP
Parole: viewed as a decision under uncertainty
Journal of Industrial Engineering Vol XVII No 8

18 R H ROY
An outline for research in penology
Operations Research Vol 12 Jan-Feb 1964

END